

# Applying piezometric evolution indicators to facilitate stakeholder's participation in the management of groundwater-dependent ecosystems. Case study: Fuente de Piedra playa lake (southern Spain)

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**Abstract** The impact derived from the exploitation of natural resources can be quantified using statistical indicators. We analyse the groundwater level evolution of jeopardised aquifers using the Temporal Variation Index and the Piezometric Situation Index. The application of both piezometric indicators to the aquifers linked to the Fuente de Piedra playa lake (southern Spain) allows us to investigate their suitability to manage groundwater resources in order to preserve its associated ecosystems. The results obtained showed that the aquifers, a detrital aquifer enclosed within Miocene–Quaternary rocks and two carbonate aquifers formed by Jurassic units, show a dissimilar piezometric level drop. In the Miocene–Quaternary aquifer various sectors are under strong pressure and piezometric levels do not recover after rainy periods. In the Jurassic aquifers, the piezometric level drops continuously over time. In view of these results, we recommend an urgent limitation of the groundwater extraction from the carbonate aquifers. This case study proves that piezometric indicators

constitute a valuable tool to managers and stakeholders for identifying sectors affected by overexploitation and, thus, help to design management strategies and public participation to preserve these types of ecosystems in the future.

**Keywords** Sustainability indicator · Piezometric evolution · Aquifer

## Introduction

Groundwater is an essential part of the hydrological cycle and a basic resource to meet the needs and activities related to the environment and human welfare. Vra & Lipponen (2007) have indicated that sustainable development ensures groundwater quantity, quality and safety as a strategic resource for guaranteeing the existence of life, economic development and the maintenance of aquatic ecosystems dependent on groundwater. According to UNESCO, to achieve sustainable development of this resource, it is necessary to follow the ideas of the so-called Integrated Water Resources Management (Vra & Lipponen op.cit.). Such an approach must integrate economic, ecological, social aspects, and therefore public participation is essential. It is well known that the protection of the environment requires the participation of the whole society. Thus it is necessary to create effective communication between the technical scientific community and various

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stakeholders. Regarding water resources this involves, amongst others, politicians, planners, managers, users and the general public.

Related to this question, the indicators can and should help establish effective communication between different groups of users. Now, what is an indicator? Although there is no official definition, one of the most common was made by Bauer (1966), “social indicators are statistics, statistical series or any kind of indication that facilitates us to study where we are and where are we going with respect to certain objectives and goals, and evaluate specific programs and determine their impact.”

When the indicators are applied to the analysis of natural resources, its most common use is the description of the state of the resource. Thus, regular measurement of indicators over a period of time (which shows trends) can help provide information about the operation and status of a system. Another primary function is communication. An indicator can be a useful tool for communicating to the public in an understandable way the state of a system, its response to external changes or changes in management, etc. At the same time, it can be a tool for evaluation, since the indicator serves to compare the current state with a reference condition.

In this study, environmental indicators have been applied to evaluate the quantitative status of the groundwater in the Fuente de Piedra *playa*-lake (southern Spain). A *playa* lake, as defined by Rodríguez-Rodríguez (2007), is a shallow water body without outlets and with a closed watershed of permeable or semi-permeable materials. A *playa* lake can thus recharge the underlying aquifer or aquitard (freshwater *playa* lakes), or can be a discharge area of ground water (saline *playa* lakes), depending on the position of the piezometric level. We used the record of six piezometric level control points located within the watershed of the *playa* lake and a water level recorder placed in the lake, during a thirty-year period (1983–2013). To analyse the groundwater status and trends in the *playa* lake, changes in water levels have been analysed by means of two indexes: the temporal variation index (TVI) and the piezometric situation index (PSI). Results achieved after applying these indexes offer clear and valuable information for technicians and non-specialists. These environmental indicators have proved to be of great utility as a tool

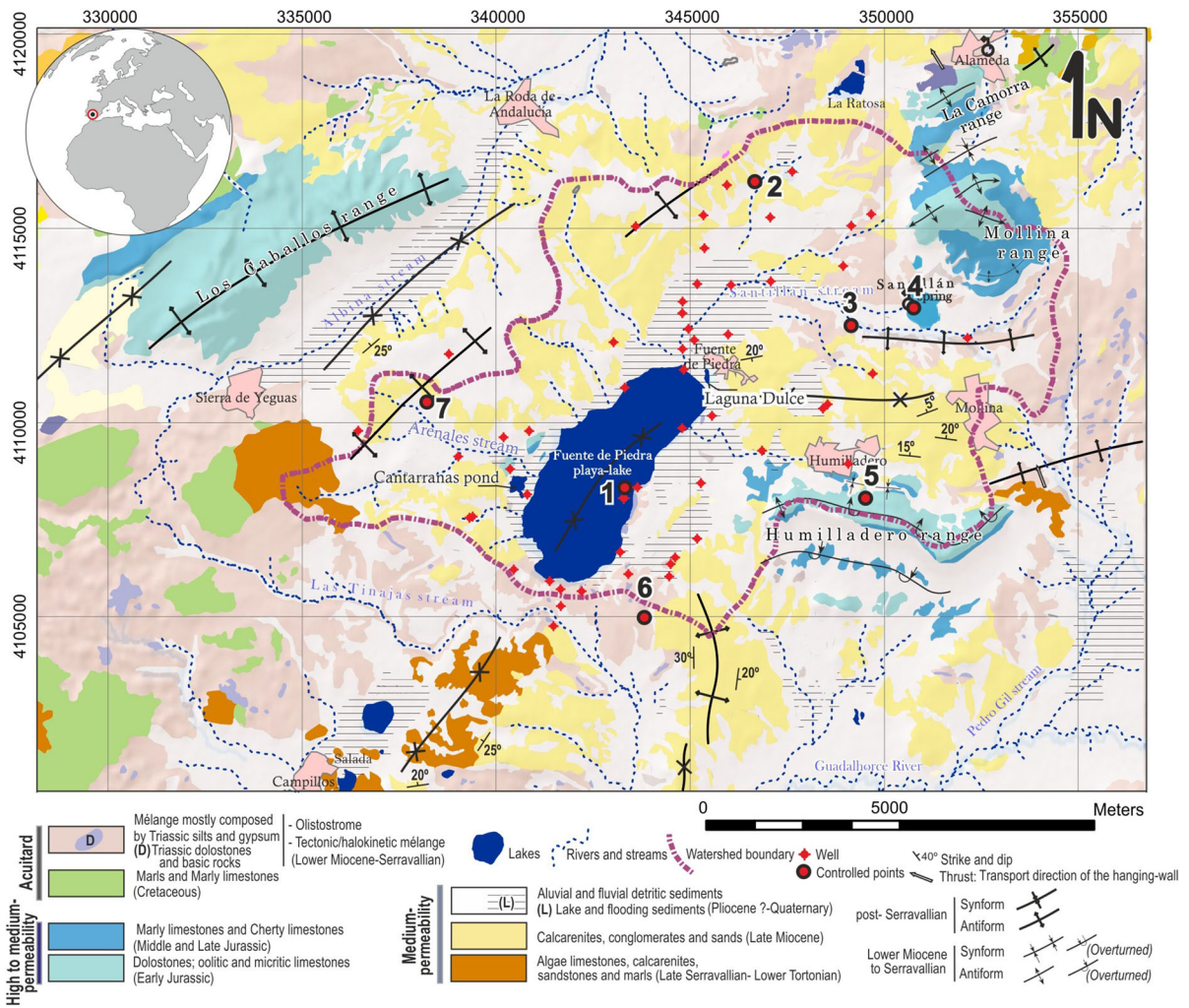
for groundwater management, especially for public participation processes (Van der Gun et al., 2007).

Our work has had two main objectives. Firstly, to apply environmental indicators for the analyses of the quantitative status of a jeopardized groundwater body related to a European *playa* lake with a huge environmental significance. Secondly, to develop a tool that allows managers, even those with limited hydrogeological training, to understand the hydrogeological and hydrological relationships controlling the evolution of lakes, therefore contributing to making correct decisions to preserve the associated ecosystems.

## Materials and methods

The Fuente de Piedra *playa* lake is a Natural Reserve located in the northwest of the Malaga province (southern Spain), at a height of approximately 410 m. The Natural Reserve is within the external zone of the Betic Cordillera (Fig. 1) and four ephemeral streams flow into the lake. The principal characteristic of the wetland is its endorheic nature, along with its extreme salinity (41 g/l of median salinity; Rodríguez-Rodríguez et al., 2010) and its temporal character. The most numerous vertebrates in the Fuente de Piedra area are the birds, with more than 170 catalogued species, mainly water birds. Currently it is the most important breeding area for the Pink Flamingo (*Phoenicopterus roseus*) in the Iberian Peninsula and, together with the Camargue (France) colony, the most relevant of the western Mediterranean and the northwestern Africa zones (Rendón et al., 2001). It is also a relevant nesting and breeding zone for other bird species such as the Gull-billed Tern (*Gelochelidon nilotica*), which has its biggest and most stable population on this wetland in the whole of Europe.

The endorheic watershed has an extension of 150 km<sup>2</sup>, and the mean flooding surface area extension of the *playa* lake is about one-eighth of its surface area. It has an average precipitation of 457 mm/year, and a mean value for runoff plus recharge in the zone of 99 mm/year (Rodríguez-Rodríguez et al., 2010). The runoff plus recharge contribution generated in the endorheic basin justifies the existence and the hydroperiod of the lake. The endorheic watershed encloses different aquifers that also extend beyond from the



**Fig. 1** Study site and structural—hydrogeological sketch

closed basin, which we will discuss later. Therefore, these aquifers partially collect water from sectors located outside the watershed boundary, as depicted in Fig. 1. Runoff, direct rainfall and aquifer discharge are the main water inputs to the lake, whilst direct evaporation is its only way out. Groundwater outflow (i.e. groundwater recharge) does not take place in this type of *playa* lake. The lake is the lowest point of the watershed, so it is the discharge area for all the aquifers forming the groundwater body (Linares, 1990; Linares and Rendon, 1998).

As far as the origin of the closed depression that forms the watershed of Fuente de Piedra *playa* lake is concerned, this is still under debate, however we can mention two principal hypotheses. Firstly, the depression where the wetland is placed may have been

caused by collapse and subsidence processes associated to karst evolution, as the karst process develops on marls, clay and silts that also enclose gypsiferous-saline materials (Lopez-Geta, 1998). Secondly, the watershed may have a tectonic origin. Following this hypothesis, the depression could be a subsidence zone, such as those which occur in other zones in the Betic Cordillera. This Cordillera is currently tectonically active orogeny, so active deformation structures may have an incidence in the topography that can even be quantified by using geomorphic indexes (Pedrera et al., 2009). The Quaternary sediments and the *playa* lake coincide with a synform and their boundaries with the trace of the contiguous antiforms (Fig. 1). Therefore, we propose that these endorheic basins, which are placed above the frontal part of the Betic

Cordillera, are controlled by NW–SE regional shortening and the formation of ENE–WSW upright open folds (González-Castillo et al., 2015). Nevertheless, some local dissolution phenomena are taking place on the Triassic gypsums outcropping in the basin. Hydrogeology is conditioned by the nature, size and structure of the aquifers located within and close to the lake's watershed. In the watershed, there are different geological materials that condition the existence of different kinds of aquifers.

The Mollina-La Camorra aquifer constitutes Jurassic dolostones and limestone, which are very permeable due to fracturing and karstic processes. During its natural regime, this aquifer has two principal drainage points at the same height (447 m a.s.l.). In the northern part of the aquifer, there is the Alameda spring, which discharges into the Guadalquivir basin. In the southern part, the Santillan spring discharges under natural conditions towards the wetland. The mean recharge rate of this aquifer, mostly rainfall infiltration, has been measured as 2.3 hm<sup>3</sup>/year (Lopez-Geta, 1998). During the first decades of the twentieth century, 1.2 hm<sup>3</sup>/year were discharged through the Santillan spring to the lake. The intense exploitation exerted upon this aquifer has produced the disappearance of this flow since the 1980s (Linares et al., 2002).

The Humilladero aquifer consists of Jurassic dolostones and limestones with a high-permeability that have been confirmed by pumping tests. Direct precipitation recharge has been estimated at 1 hm<sup>3</sup>/year. The absence of any relevant spring makes the groundwater flow pattern of the aquifer difficult to be determined. Nevertheless, geological data suggest the continuity of the aquifer towards the west, where it would reach a height lower than the lake being covered by Miocene and Quaternary sediments. Discharge from the aquifer may be taking place toward the playa lake which is hidden below these sediments.

The Miocene–Quaternary aquifer is the most extensive of the lake's hydrologic system. It is composed of Miocene bioclastic sandstones and sands, and Quaternary gravels, sands and silt. Its lateral limits nearly coincide with the boundary of the lake's watershed. The aquifer shows important lateral facies changes, which affect the spatial pattern of permeability. Aquifer recharge is by the rain water infiltration and the infiltration of some runoff water that is generated during the rainy season on the streams that evacuate their water into the lake. The plentiful

available piezometric information regarding this aquifer, from the 1970s, shows that in a natural regime the groundwater flow is radial and convergent to the lake.

As for the hydrology of the playa lake, it is filled directly by precipitation and runoff water from the ephemeral rivers, gullies and rills during the rainy season, apart from the natural groundwater discharge from the mentioned Jurassic aquifers, which are interconnected. The lake has an ellipsoidal shape, and the flooded basin may reach a maximum surface of more than 1800 ha. There is a 2–3 m wide ancient channel built during the saltpan exploitation period to avoid water entering the lake and to protect the adjacent crops from overflows. It surrounds the lake's shore. Currently, it does not have any function, it has been partially filled with sediments and is in continuity with the lake in exceptionally rainy years, when the channel overflows. Near the *playa* lake there are two small ponds. The nearest one is the Laguna Dulce ("the Freshwater Lake"), which is small, ephemeral and located in the northwest section. The Cantarranas seasonal pond is located to the southwest and is smaller (see Fig. 1). It is a fresh water pond fed both by precipitation and the overflow of the nearby Arenales stream. These ponds provide the ecosystem water habitats with different salinity levels, and they are essential to maintain the biodiversity.

The mean yearly precipitation of the Fuente de Piedra *playa* lake surroundings is 457 mm/year for the period 1962/1963–2012/2013, with a standard deviation of 137 mm/year. The median value is 436 mm/year, with 25 and 75 percentiles of 363 and 528 mm/year, respectively. The dry year corresponds to a value of 363 mm and the wet one to 528 mm. The annual precipitation variability is remarkable. The mean annual temperature corresponding to the period 1962/1963–2012/2013 is 16.6°C, with a standard deviation of 0.75°C. The median value is 16.7°C with 25 and 75 percentiles of 16.1 and 17.2°C, respectively. The annual mean of the last two years is lower than the mean value of the period and it is lower than the 25th percentile value of the statistics.

Regarding methodology, piezometric records of representative control points and data from the water level recorder placed within the lake have been used (Fig. 1). Selection was made after the analyses of long-time series (since 1980 to date) of more than 40 wells and drills within the watershed. The study period

was from 1983 to 2013. Identification and type of aquifer in these control points are specified in Fig. 1. From all these records, there are continuous measurements from the water level recorder installed in the *playa* lake. These started in 1983 and measured the daily water level until 2013. All the wells are level, so every depth level measurement has been transformed to elevation above sea level, in metres (m a.s.l.). Index application and statistical treatment of the piezometric records of the Fuente de Piedra *playa* lake have been done by sectors; therefore, each of the control points are treated and analysed independently.

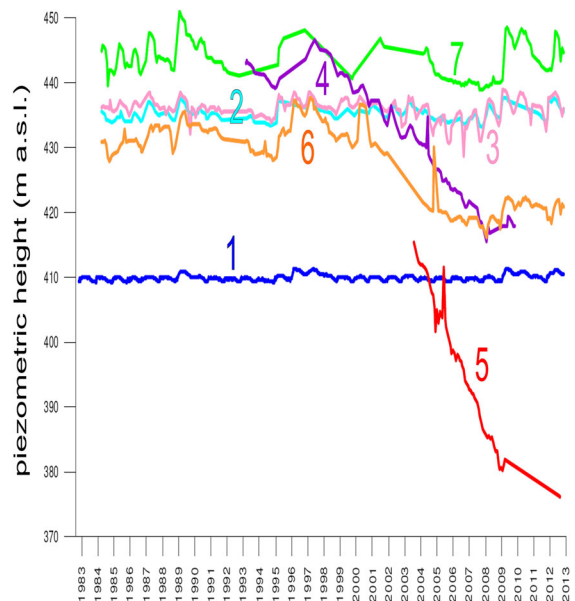
To apply the groundwater quantitative status indicators, the following indexes have been elaborated and applied for the first time in this *playa* lake:

- *Temporal variation index (TVI)* Piezometric data are plotted versus time, showing the temporal evolution of this variable. Accumulated deviation from the average of precipitation is also represented, to check the amount of correlation of both variables. This chart provides general information about the functioning and hydrologic behaviour of each control point during the considered study period.
- *Piezometric situation index (PSI)* For the application of this index, a statistical treatment of the piezometric data recorded during a representative period of time (at least 30 years) is required. It is necessary to obtain mean, standard deviation, median, tenth and ninetieth percentiles of the piezometric data corresponding to each month of the year during the historical period studied. Once this statistical analysis is done, we proceed to represent the monthly evolution of the piezometric records from the last year we have data (for this study, year 2013). This can thus be compared with the mean, mean  $\pm$  standard deviation, median and monthly tenth and ninetieth percentiles of the piezometric registers of the whole control period. This index allows us to see clearly how the levels are evolving during the last hydrological year and allows the comparison with the entire recorded period.

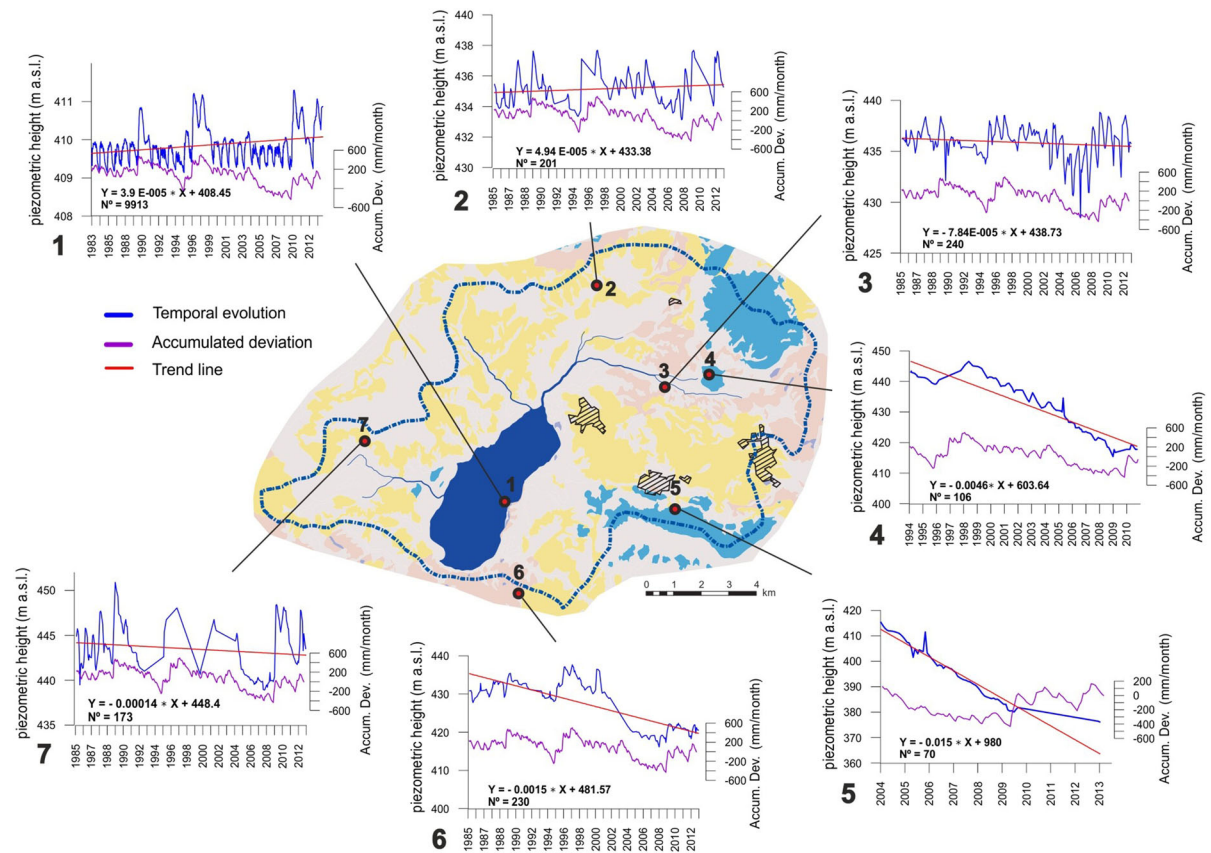
## Results

The variation of the groundwater storage of the Fuente de Piedra Lake is explained via the indexes TVI (Fig. 3) and PSI (Fig. 4) described above from 1983 to

2013. First of all, the temporal evolution of the piezometric level of each of the control points is shown in Fig. 2. The groundwater evolution presents annual and inter-annual oscillations in every piezometer. Three kinds of responses are clearly distinguished during the study period. Firstly, the northern and western piezometers (2 and 7) do not present a significant decreasing trend and the level ascents and descents are related to recharge and discharge annual events, which are typical of unconfined aquifers systems (see TVI, Fig. 3). Secondly, the Santillan stream piezometer (3) presents an evolution with less significant annual oscillations until 2002 and afterwards greater annual oscillations. Finally, the three piezometers related to carbonatic aquifers of the NE (4: Mollina) and SE (5: Humilladero and 6) present a clearly decreasing trend from 1999, with a more than 10-metre decrease in 10 years (see TVI, Fig. 3). From 2009, a slight recovery seems to be recorded. The Humilladero piezometer (5) is the one that shows a more worrying situation, as its level from 2004 is under 409 m a.s.l.; below the position (409,1 m a.s.l.) of the Fuente de Piedra *playa* lake floor. This difference in water level is significant, because the relative position of the water level in piezometer 5, below the *playa* lake floor, may lead to a hydraulic gradient inversion in this sector.



**Fig. 2** Temporal evolution of the water level in the piezometers and the *playa* lake



**Fig. 3** Temporal variation index (TVI)

The level evolution on the water level recorder (1) during the study period can be observed in more detail in Fig. 3 (TVI index). Compared to the piezometric oscillations, which include ranges over 20 m at the same point during the study period; in the lake this range is smaller: 2.16 m. This is because the oscillations are produced on a free water sheet when the lake is flooded and not on a porous medium. Furthermore, when the lake is dry, the level does not decrease below 40 cm under the soil. The explanation for this hydrological behaviour may be due to the depth of the capillary fringe being broken at this point, and no more evapotranspiration is produced or, on the other hand, because a dynamic equilibrium between evaporative output and groundwater discharge is reached at this depth. The second hypothesis is the most likely, as a rapid rising of the water level in the playa lake floor producing the humidification of the surface has been noted during cloudy days in summer. The Fuente de Piedra *playa* lake stays flooded 74% of the time,

normally from October to June during mean hydrologic years. During summer months, the lake is usually dry. Only once in every five summers has the lake remained flooded (1990–1997–1998–2010–2011 and 2013), coinciding with rainy years. Neither a clear trend to longer drought periods at the lake in recent years is observed, nor the opposite. The median value of the water level above the *playa* lake floor is 25 cm. We believe the median value is more representative than the average to indicate the most frequent water level state in the *playa* lake. The median is used as a measure of location for a skewed series of data, and when we want to minimise the importance of outliers, e.g. when there is a rapid rise in the water level during very rainy periods. The maximum water level value registered during the analysed period is 1.76 m (last days of March, 2010) and the minimum  $-0.4$  m below the *playa* lake floor (first days of November, 1995).

For piezometer #6, the control period is from 1985 to 2013 and it presents piezometric levels from 416 to

**Table 1** Main statistics in the piezometers and the *playa* lake

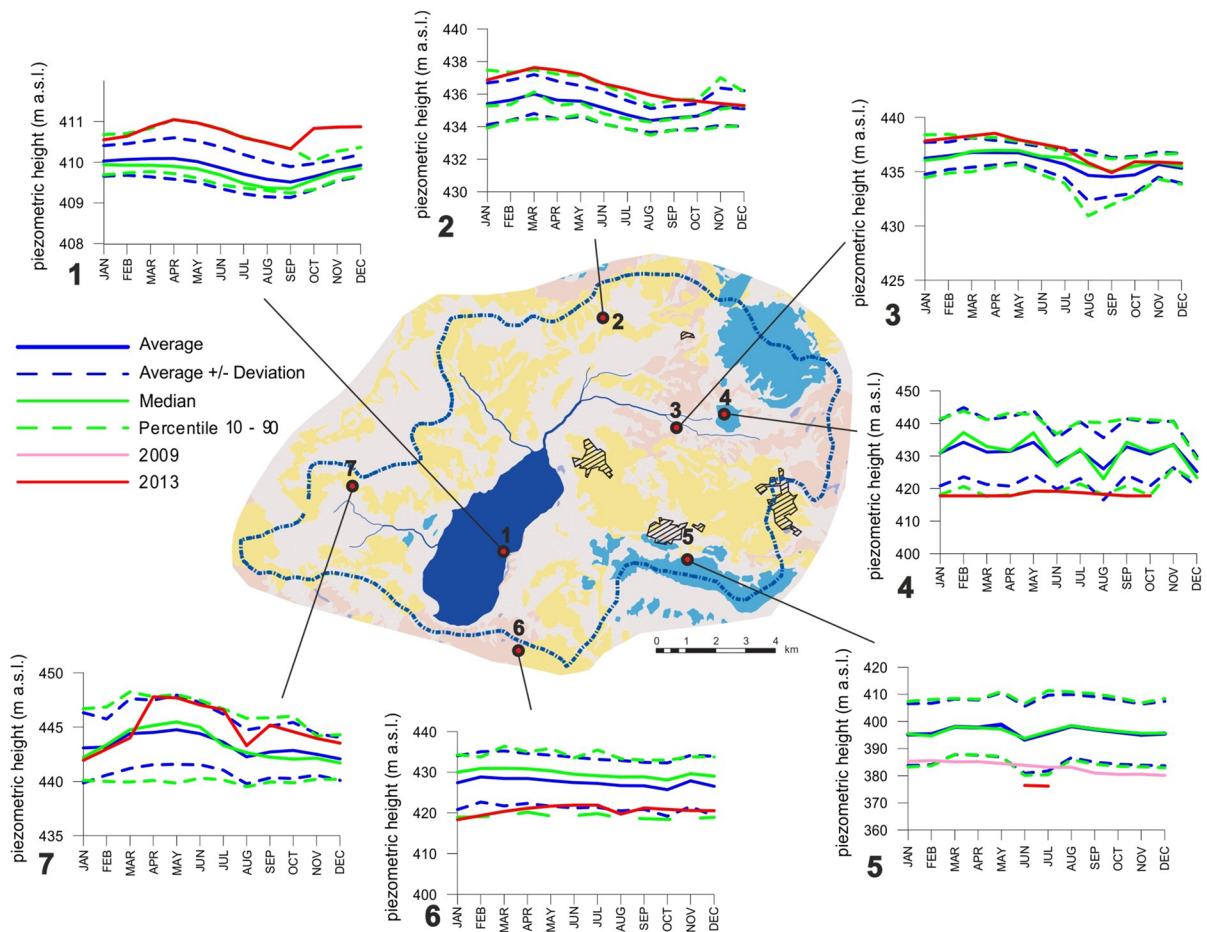
Piezometer number	1	2	3	4	5	6	7
Period	1983–2013	1985–2013	1985–2013	1994–2010	2004–2013	1985–2013	1985–2013
<i>N</i>	357/9913	201	240	106	70	229	173
Min	409.2	433.1	428.6	415.4	376.2	416.1	438.9
Max	411.3	437.7	438.8	446.5	415.3	437.7	450.9
Mean	409.9	435.2	435.9	431.7	396.4	427.5	443.4
Mean 2013	410.7	436.6	436.9	417.7	376.3	420.8	445.3
Median	409.8	435.7	436.1	432.9	397.1	429.4	443.3

438 m a.s.l. (Table 1). The evolution of the piezometric registers (Fig. 3, TVI index) is noticeably down according to the trend line of this figure. Piezometer #7 is located in the western part of the watershed, next to the boundary limit (Fig. 1). The control period is from 1985 to 2013, and it presents piezometric levels between 439 and 451 m a.s.l. (Table 1). A general maintenance of the piezometric level can be appreciated in Fig. 3 (TVI). 1997 has the higher median value (448 m a.s.l.). The piezometer located in the north of the lake (#2) is next to the watershed divide (Fig. 1). The control period is from 1985 to 2013, being a fairly complete series. It presents extreme piezometric levels between 433 and 438 m a.s.l. The trend line has a gentle positive slope (Fig. 3, TVI index). In Fig. 4 (PSI index), a comparison of the monthly evolution of the piezometric records is shown. It can be observed how the mean and median are overlaid throughout the graph. Figure 3 shows the TVI index at the control point placed over Mollina Sierra (#4). This piezometer is upstream of the Santillan stream, in the northwestern part of the watershed. The decreasing trend in the water level is 1.3 m/year for this piezometer. The highest record of the water level in piezometer #3 (Fig. 3) was done in January, 2010 and the lowest in March, 1985. The trend line represented in Fig. 3 indicates a general maintenance of the water level for this control point, with a gently negative slope. In addition, the water level in this piezometer presents little variation for the annual median. Piezometer #5 is placed in Jurassic materials from Humilladero Sierra. The study period is very short, and the series starts in 2004 (Table 1). The evolution of the piezometry at this point is clearly descendent. The descent rates in the water table are even higher than the ones for the

Mollina Sierra, with 4.3 m/year. This evolution is conspicuous in the trend line which is represented in Fig. 3.

## Discussion

The discussion of the piezometric information analysis is presented by sectors. This was decided because, as commented above, the hydrological behaviour is quite different depending on the location of the piezometer in the watershed and its connection with the Miocene–Quaternary materials or the Jurassic carbonate aquifers of Mollina-La Camorra and Humilladero. Such different behaviours have been previously stated by several authors for this *playa* lake (Lopez-Geta, 1998; Kohfahl et al., 2008). First of all, the evolution of the water level in the lake is strongly dependent on the precipitation regime, as commented previously, and very little by regional groundwater discharge conditions. There is an immediate response from the piezometric level to the lack or existence of rainfall in the watershed. In any case, there is also a contribution by the groundwater flow, which is much more inertial and comes from the Miocene, Quaternary and Jurassic aquifers outcropping in the watershed. This groundwater discharge is produced through the shores and the bottom of the lake, a process that also continues by capillary action, when the lake is dry in summer, from the surface up to –40 cm below. The discharge by evaporation of the system has been estimated in a range from 8 to 11 hm<sup>3</sup>/year as an average (Linares et al., 2002). An upward trend of the water level can be appreciated from 1983 to 2013. This may be explained by some rainy periods during recent years.



**Fig. 4** Piezometric situation index (PSI)

The piezometric evolution in the carbonatic aquifers evidence the accumulated level drops and an intensive exploitation of the groundwater, in both the Molina-La Camorra and Humilladero aquifers. This situation is not an exception in the region. In fact, in nearby aquifers, other authors (Lambán et al., 2011) have also applied groundwater sustainability indicators to Sierra de Becerrero, finding an alarming decrease in the piezometry as well as a quality degradation of the groundwater due to intense exploitation of the water resources. In the case of the Molina-La camorra aquifer, it has been found that from 1999 the piezometric level started to fall in this zone. Precipitation does not compensate the water output in this aquifer. Therefore, the piezometric level decreases every year. This hydrodynamic situation suggests that a change of flow direction in the groundwater has occurred, meaning that the Molina-

La Camorra aquifer, which originally fed the Miocene–Quaternary aquifer, is now draining its water. This Miocene aquifer is contaminated with nitrates of agricultural origin, so a possible affection in the water quality of Molina-La Camorra aquifer may be taking place. In the case of Humilladero aquifer, the continuous level has decreased since 2004, therefore, the aquifer's groundwater reserves are now decreasing rapidly. The constant decline in the piezometric level indicates that there is a problem affecting this aquifer and that action should be taken, because the level is not being recovered, even during high precipitation years. In this piezometer, the piezometric level is lower than the *playa* lake bottom. Therefore, a hydraulic gradient inversion is likely to be occurring, although this is difficult to corroborate for the short term. However, in the long term, the contribution of groundwater discharge from Humilladero to the Fuente de Piedra



Lake could be diminishing or even being completely interrupted.

The evolution in the piezometers in the Miocene–Quaternary materials is parallel to the trend in the accumulated deviation of the precipitation, with some exceptions that will be commented later on. The maximum water levels are reached in the spring months and their minimum in summer months; so the regulation of the precipitation in this aquifer is noteworthy. The behaviour of the piezometer located at the Santillan headwaters is very peculiar. The piezometric level was stable until 2002 and since then annual fluctuations have been sharper. Currently, the piezometric level in the Sierra de Mollina-La Camorra aquifer is at the same height as the one in Santillan. In 2002, for the first time the piezometric head was located below the level of the Miocene aquifer. Therefore, the oscillating behaviour in the piezometric level at the Miocene aquifer may be explained as a consequence of the intensive exploitation in the Mollina-La Camorra aquifer, which would change from discharging to the Miocene aquifer; thus modulating oscillations at the Santillan headwaters piezometer to an opposite situation, where the Miocene aquifer is partially recharging the carbonate aquifer of Mollina-La Camorra, so that the annual oscillations would be higher. The discharge to the Santillan stream should have been reduced as a consequence of the gradient reversal since 2002 and, also, probably the runoff contributions to the Fuente de Piedra *playa* lake. Indeed, the levels recorded in the *playa* lake during the period 2004–2008 were relatively lower than previous periods with similar precipitation, and the daily oscillation degree in the lake's level was higher as well. From 2009 onwards, due to the abundant precipitations, the *playa* lake has experienced several years of flooding.

The analysis of the temporary evolution of the water level during the period analysed in this paper (1983–2013) has allowed the evaluation of the significant temporal variability of this hydrologic system and how actions in the watershed affect, in the long term, the *playa* lake's hydro-period. The system's dependence on groundwater may be masked by high precipitation periods that cause a rapid rise of the water level and also the recharge of the associated aquifers. In addition, the results obtained by some authors (Kohfahl et al., 2008) that have numerically modelled the hydrochemistry of the *playa* lake showed

the existence of convection cells below the lake as well as recycled brines at the lake edge. A restricted subsurface discharge of meteoric freshwater towards the lake, owing to the limited lateral extension of permeable sediment layers was also found.

## Conclusions

The analysis of the water level evolution in different control points during the analysed period reported in this paper (1983–2013) has allowed us to check the temporal variability of the Fuente de Piedra *playa* lake hydrologic system. First of all, two kinds of aquifers have to be clearly differentiated: the Miocene–Quaternary aquifer and the carbonatic Jurassic aquifers. The monitoring and study of the temporal evolution of the piezometric level on the different control points has allowed us to make these considerations: the piezometric levels in the Miocene–Quaternary aquifer are stable and they show a temporal evolution that is parallel to the accumulated deviation from the average of the precipitation. These areas coincide with the southern sector of the lake, with the central area between Sierra de Mollina-La Camorra and Humilladero, and with the west-southwest sector. However, there are other sectors which indicate that there is an accumulated decrease in the piezometric level, normally close to the Jurassic aquifers. It is in the latter where there is an evident drop in the piezometric levels. They are on the eastern sector of the watershed and they feed the Miocene–Quaternary aquifer under natural conditions: the Mollina-La Camorra is in the northeast and Humilladero to the southwest. The Mollina-La Camorra and Humilladero aquifers have changed from feeding the Miocene–Quaternary aquifer, and thus the lake, to become the drains of the system. The piezometric level drop in such aquifers has resulted in a change in the hydrologic boundary of the *playa* lake (eastern side). This fact could cause a water input decrease into the *playa* lake, both from Jurassic and Miocene–Quaternary aquifers, even if this decrease maybe masked during wet periods, due to the rapid response of the *playa* lake to the incoming runoff. The significant decreasing trend of the piezometric levels in the Jurassic aquifers will require an urgent intervention from the relevant administration in order to manage and limit the groundwater extraction. It is considered essential to build new piezometers in

the carbonate aquifers to control the piezometric level in different sectors. Moreover, it should be kept in mind that the populations from all the nearby towns satisfy their urban water demand from these aquifers, with no alternative for the moment. To sum up, it is clear that the hydrogeological knowledge of the aquifers has to be updated and be further developed in the future. A suitable solution for the current unsustainable exploitation that is taking place in the system must be provided as soon as possible.

Finally, the use of the piezometric indicators presented in this paper helps to simplify and therefore, to understand the abundant piezometric information existing in the Fuente de Piedra watershed. Figures 2, 3 and 4 presented in this paper display the different responses of the groundwater level in the various sectors of the Miocene–Quaternary aquifer, in the carbonate aquifers of the watershed and, also, the response of the water level in the *playa* lake. The use of the indicators TVI and PSI allows managers and planners of this wetland and other similar ecosystems to understand and share the results of monitoring these water bodies, thus assisting in the process of public participation in the management of water resources, as established by European regulations in the Water Framework Directive. The application of management measures and strategies to protect aquatic ecosystems should therefore include the analyses of the indicators that have been applied in this case study. Nevertheless, providing general threshold values to be applied for restrictions in any other water body needs a previous in-depth hydrogeological knowledge of the system and the interpretation of the piezometric trends observed in each case.

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